The Wave-Zone Benthic Communities of Onondaga Lake: A Highly Disturbed Aquatic System in Central New York

by
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V. Abstract

Wagner, A. Bruce. The wave-zone benthic communities of Onondaga Lake: A highly disturbed aquatic system in Central New York.

The wave-zone benthic macroinvertebrate community of the littoral zone of Onondaga Lake was characterized based on samples taken in the summer of 1989. Onondaga Lake is an industrially polluted, hypereutrophic lake in metropolitan Syracuse, NY. The littoral zone is highly impacted by industrial deposits and has a limited population of macrophytes. The macroinvertebrate community of the lake is characterized by unusually low species (taxon) diversity. The chironomid community is particularly depauperate. The macroinvertebrate community of the lake, and the chironomid assemblage in particular, is comprised of forms known to be tolerant of pollution. The community is dominated by chironomids; other significant components include oligochaetes and the amphipod (*Gammarus fasciatus*), forms tolerant of unnaturally high salinity. Overall population densities are similar to those in other lakes. The degraded condition of this community reflects the combined effects of the polluted condition of the water column and the alterations to the near-shore sediments caused by earlier industrial discharges.

Key words: wave-zone, Onondaga Lake, macroinvertebrates, hypereutrophic, chironomid, salinity.

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VI.   Introduction

A.   *The Study Site: Onondaga Lake*

Onondaga Lake has been described as the most polluted lake in the United

States (U.S. Senate 1989, Hennigan 1990). It has been the principle receptacle for

domestic waste and much of the industrial wastes from the metropolitan area

throughout the early development of central New York (from the   700's - present)

(Effler 1996). The greatest industrial impacts to Onondaga Lake are associated with

soda ash and chlor-alkali production (the Solvay Process) at Allied Signal chemical

manufacturing facility near the western shore of the lake. Over the facility's one

hundred and two years of operation, thirty other chemicals (various acids, bases,

chlorine gas, and chlorinated benzenes) were also manufactured. Soda ash production

generated soluble ionic waste (Cl^-, Na^+, Ca^{2+}) which drained into the lake along with

large quantities of solid waste, mostly $CaCO_3$, CaSi, MgOH, CaO and $CaCl_2$ (Solvay

waste) (Kulhawy *et al.* 1977). These waste deposits surround 30% of Onondaga Lake

and a large portion of the lower reaches of Ninemile Creek (Figure 1). More than 8.1

km^2 are covered with Solvay waste from 2 to 21 meters deep. The residual annual

loading of ionic waste from the Ninemile Creek waste beds in 1989 was about 0.14

million metric tons (Effler 1996). Loadings from the older waste beds have not been

quantified. The chloride release from Onondaga Lake represented approximately 12%

of the total chloride load to Lake Ontario for the period 1970-1981(Effler et al.

985). The soda ash facility was closed in 1986. Mercury (Hg^{2+}) was released into

the lake as a waste product of the chlor-alkali process. Approximately 75,000 kg of

mercury were discharged to the lake between 1946 to 1970 (USEPA 1973). The

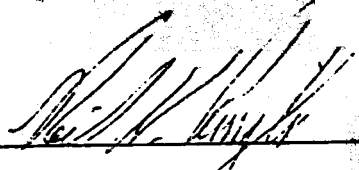chlor-alkali facility remained in operation until 1988. Other current industrial waste
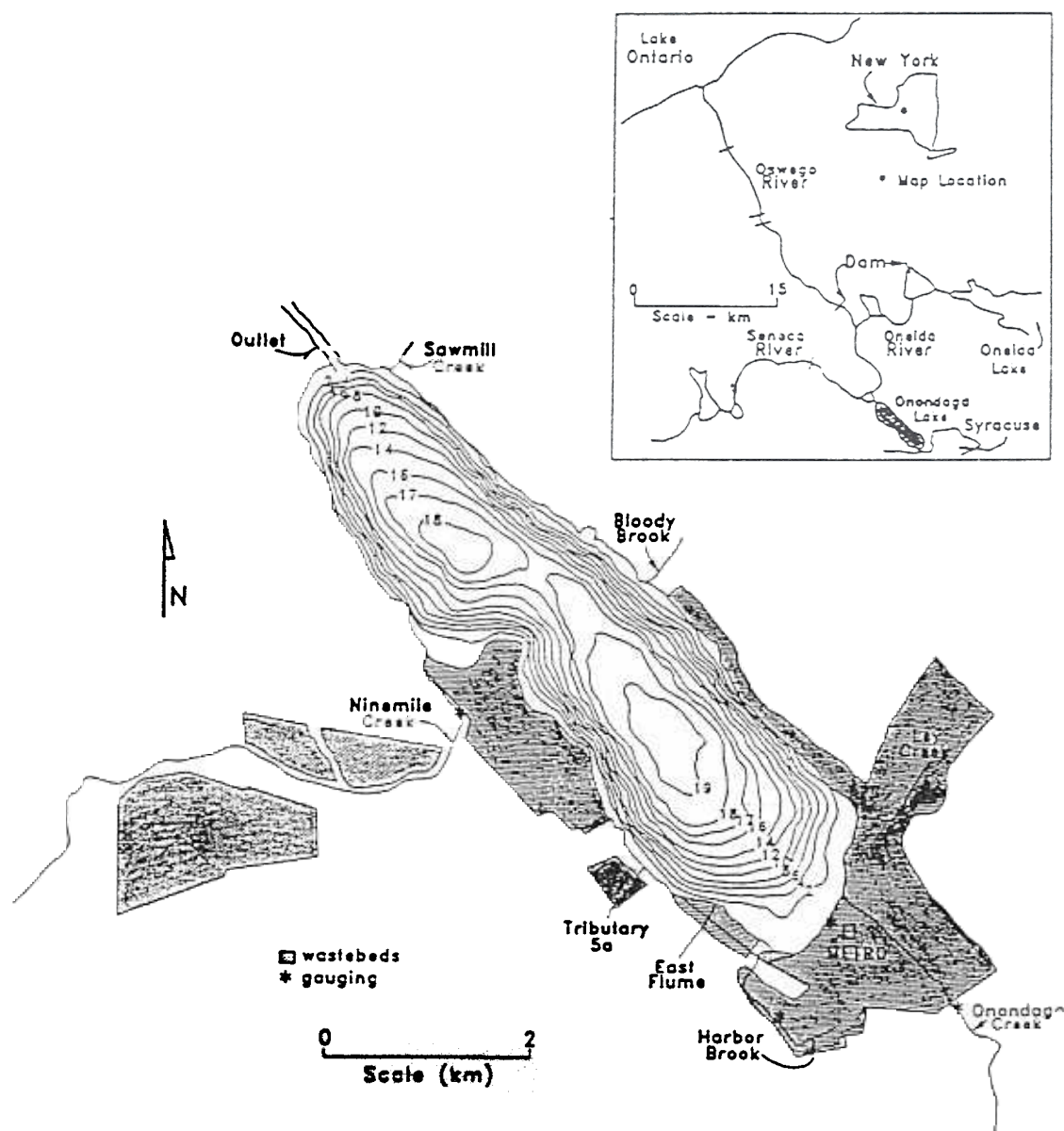
Figure 1. Map of Onondaga Lake, NY, and surrounding waste beds. Soundings
in meters (modified from Effler and Hennigan 1996)

input sources include a specialty steel plant, a large pharmaceutical plant, a candle factory, and a china factory, along with various industries related to automobile manufacturing.

During the early part of this century, possibly when the old Oswego canal was filled-in during the 1920's or 1930's, waste porcelain (broken) containing lead was dumped along the eastern shoreline. The broken pieces are visible today along the Onondaga Lake Park shoreline. Current inputs of domestic waste to Onondaga Lake are primarily from the Metropolitan Syracuse Sewage Treatment Plant (METRO) with smaller quantities received irregularly from Onondaga Creek and Ley Creek. These inputs will be discussed later in this paper.

More than 130 studies have been conducted on the lake and its watershed from the 1920's to the present; most studies have been carried out within the last ten years. Only three of the studies (Onondaga County 1971, Wagner and Effler 1993, and Makarewicz et al. 1995) dealt in any fashion with the benthic organisms of Onondaga Lake.

The Onondaga County study (1971) was very limited in this regard. Although eight Ekman dredge samples were collected (1969) at two depths at four near-shore sites, no identification or quantification of the benthic invertebrate population was reported. Chironomid larvae and ostracods were the only groups mentioned. Wagner and Effler (1993) documented the near-shore benthic macroinvertebrate communities along the north side of the lake near Onondaga Lake Park and along the Allied waste bed area on the west side during June 1989. Makarewicz et al. (1995) sampled the

phytoplankton, zooplankton, macrobenthos and ichthyoplankton of Onondaga Lake during the spring, summer, and fall of 1994. Most samples were concentrated in areas of the lake near the Allied waste beds.

My thesis characterizes the macrobenthic community as it appeared in 1989. This was three years after closure of the Allied Signal soda ash plant and before Zebra mussels, *Dreissena polymorpha*, were reported in the watershed in 1990 This study is an expansion of the analysis by Wagner and Effler (1993), including data from two more sampling dates.

B.   *Benthic macroinvertebrates*
Rosenberg and Resh (1993) defined a macroinvertebrate as an invertebrate animal with a body size of greater than 200 µm inhabiting the substratum environments (sediments, debris, logs, macrophytes, filamentous algae) of lentic (lake and ponds) and lotic (river and stream) systems during some part of their life cycle. Many taxonomic groups contribute to benthic macroinvertebrate communities, including nematodes, turbellarians, oligochaetes, crustaceans, mollusks, and aquatic insects. These communities form a large part of many food webs in aquatic environments, and thus are of major importance in the cycling of organic and inorganic constituents in these ecosystems.

Benthic invertebrates may form stable communities, particularly in lakes. Due to its relative stability, the benthic community may reflect the worst conditions that prevail at a particular location (Effler 1996). However, seasonal dynamics of individual species may result in extreme variation in numbers or biomass at specific

sites within a given year (Weber 1973, Hawkes 1979, Suess 1982, Merritt and Cummings 1984). The analysis of benthic macroinvertebrate community parameters such as density, diversity, species abundance, and species richness are useful in assessing the impacts of pollution and perturbations (APHA 1989, Resh and Unzicker 1975, Wiederholm 1984).

C. *Objectives*

This study had three major objectives:

1. To describe the wave zone macrobenthic community of Onondaga Lake.

2. To determine the effects of pollution history on community composition.

3. To determine whether sites with different degrees of perturbation had communities that reflected these differences.

4. To provide baseline information about the macroinvertebrate community for future research.

VII. Study Site

A. Onondaga Lake

The lake is located in the Oswego River Drainage Basin (lat. 43 06'54", long 76 14'34") northwest of the city of Syracuse in Onondaga County, New York (Figure

The watershed lies within a humid continental climate with an annual average of 93 cm of precipitation a year, although there is substantial annual variation (Effler 1996). The lake is oriented along a northwest-southeast axis. The outlet at the northern end flows into the Seneca River. Morphometric characteristics of the lake are presented in Table 1

Table 1. Morphometric Characteristics of Onondaga Lake, N.Y.

Length	Width	Surface Area	Volume	Mean Depth	Max. Depth
km	km	km^2	$x10^6m^3$	m	m
7.6	2	12.0	131	10.9	19.5

Onondaga is a hypereutrophic, hard water lake (Effler 1996) with unusually high salinity (Effler 1996) composed primarily Cl^-, Na^-, and Ca^{2+} (Doerr et al. 1994, Effler 1996). During the summer months the dissolved oxygen is depleted in the hypolimnion. The flushing rate of Onondaga Lake varies between three and five times a year depending on precipitation rates. One source of elevated sulfate and calcium concentrations in the surface water may be the underlying Vernon shale bedrock which contains large concentrations of gypsum, a calcium sulfate mineral (Winkley 1989). This natural source of calcium, along with massive amounts of calcium waste

generated by chlor-alkali production, contributed to the formation of lacustrine oncolites (Dean and Eggleston 1984), which cover much of the littoral zone (Figure 2). These formations are ovoid lobate or flattened cryptalgal structures that are not attached to the substrate (Figure 3). They are characterized by concentric laminations that form around a nucleus. It has been speculated that the layers are a result of photosynthetically induced precipitation by cyanobacteria and accretion (Jones and Wilkinson 1978). Some oncolites from Onondaga Lake have nuclei of whole snail shells or fragments of shell, but the vast majority surround stems of charophytes (Dean and Eggleston 1984; Wagner personal observation). However, charophytes have not been observed in Onondaga Lake since at least 1925 (Dean and Eggleston 1984; Madsen et al. 1994)

Onondaga Lake occupies part of a post glacial depression which remained after the level of glacial Lake Iroquois dropped, approximately 10,000 - 12,000 years ago (Winkley 1989). Most of the major tributaries to Onondaga Lake are contained within glacial meltwater channels and troughs composed of unconsolidated interbedded sands and gravels.

The major tributaries to the lake are Ninemile Creek, Onondaga Creek, the Metropolitan Syracuse Sewage Treatment Plant (METRO), and Ley Creek. These comprise approximately 90 % of the inflow to Onondaga Lake. The other minor inflows are Bloody Brook, Harbor Brook, East Flume, Tributary 5A, and Sawmill Creek
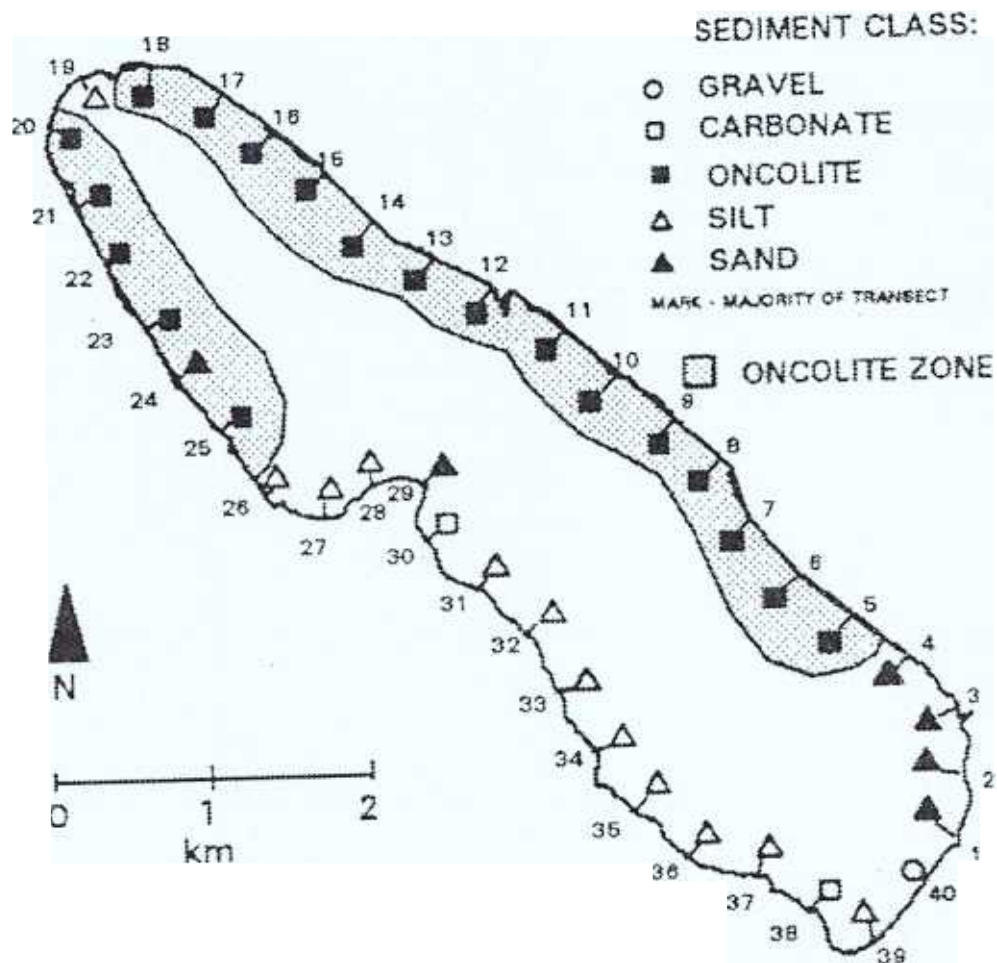
Figure 2. Map of the surficial zone sediments of Onondaga Lake (modified from Madsen et. al. 1996 in Effler 1996).
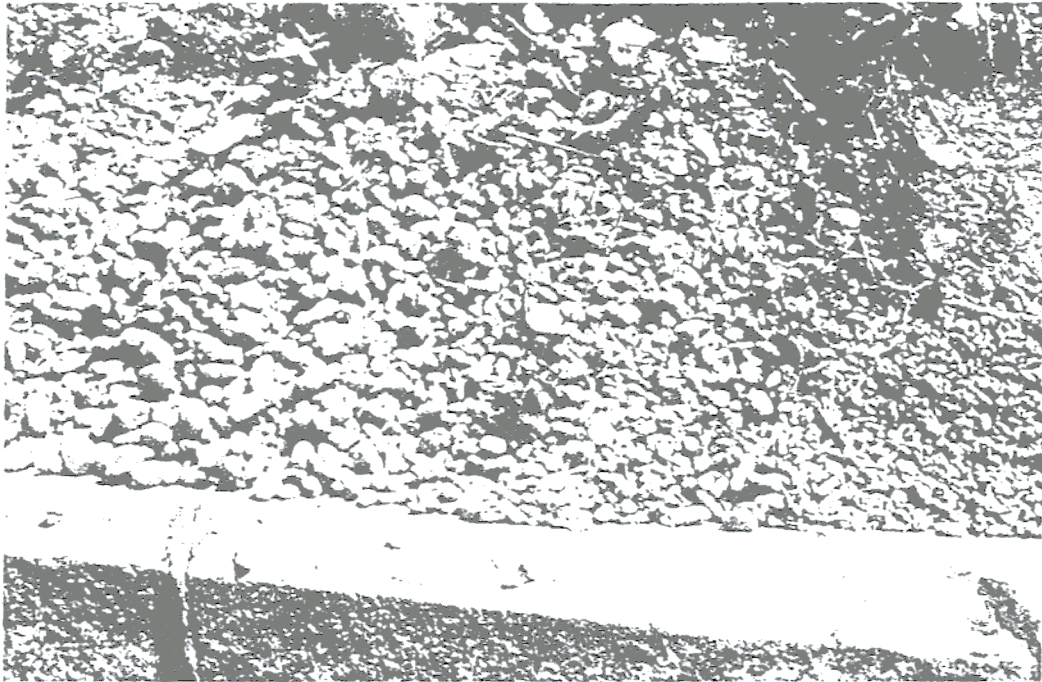
Figure 3. Photograph of oncolites from Onondaga Lake.

of the phosphorus load to the lake (Effler 1996). The New York state ammonia chronic toxicity standard, developed to protect fish against the toxic effects of ammonia, is exceeded through most of the summer in most years (Effler 1996).

Ley Creek enters at the southeastern end of the lake. Its 77.4 km^2 watershed is primarily residential and industrial. The lower reaches of Ley Creek flow adjacent to several closed landfills and industrial ponds which contain material contaminated with PCB's and other hydrocarbons (Hubbard 1996). Two CSO's also discharge into the creek, accounting for about 7% of the inflow to Onondaga Lake.

VIII. Materials and Methods

A. *Sample sites*

Four sites were selected in the near shore littoral zone of Onondaga Lake. Two of the sites (W-1,W-2) are located along the western shore on the Solvay waste beds. The other two sites (P- , P-2) are located on the east shore in Onondaga Lake Park (Figure 4). The waste bed sites (W-1, W-2) consist mainly of small chunks of Allied waste ranging in size from small pebbles to cobble (0.5 to 30 cm). This material rests on a thin, soft, sand/silt layer composed of Solvay waste with a firmer, almost cement-like, layer underneath. Sites W-1 and W-2 had sparse mats of algae (mostly *Cladophora* sp.) growing on the substrate and on the chunks of Solvay waste. No rooted macrophytes were observed at either waste bed site. The waste beds on shore immediately adjacent to W-1 appear to have been active until 1929, as where the bed adjacent to W-2 was used until 1941 The other lake shore waste beds farther from the lake were used until 1950 (Figure 5) (Hewlett 1956, Michalenko 1991). Approximately 2 m southeast of site W-2 was an area of very soft waste deposits which omitted bubbles with the odor of H_2S when disturbed. A clear 3.7 cm diameter by 120 cm long coring tube was forced into same area and removed. This core sample was approximately 110 cm long. It was Robin egg blue for most of its length with a thin white layer at the top and a thicker (2cm) black layer at the bottom I was unable to obtain assistance in identifying the exact contents of the waste bed material in this core sample.

Lake Outlet
Sawmill Creek
P-1
Bloody Brook
P-2
N
Ninemile Creek
W-1
Scale in kilometers
0   0.5   1.0   1.5   2.0
W-2
Ley Creek
Trib 5A
Onondaga Creek
East Flume
Metropolitan Treatment Plant
Harbor Brook

Figure 4. Macroinvertebrate sampling sites on Onondaga Lake.
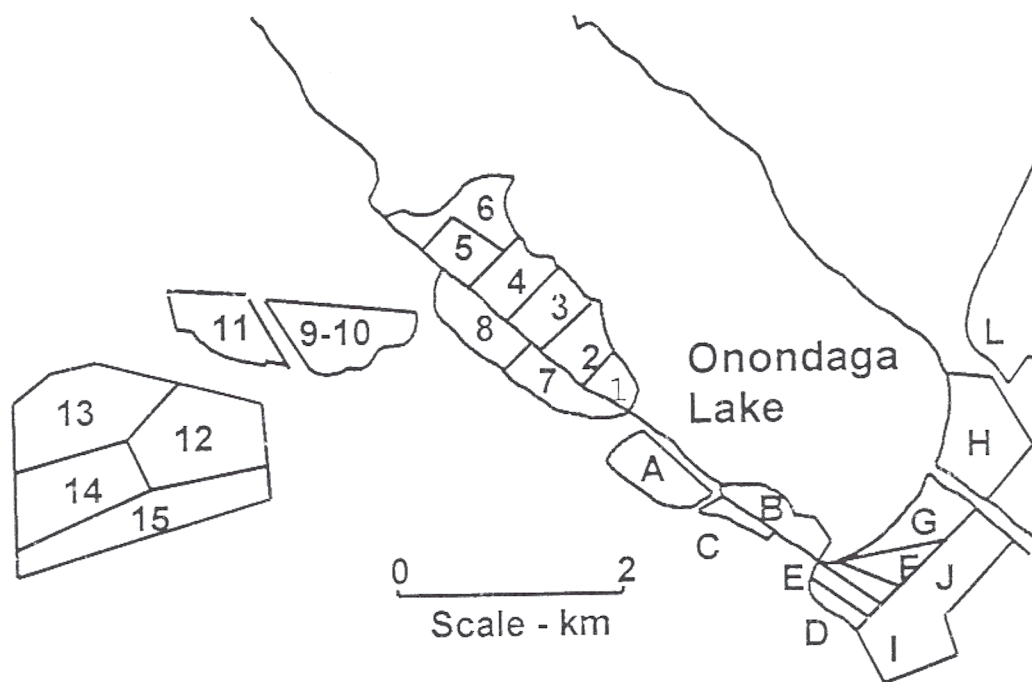
Figure 5. Aireal distribution of Solvay waste deposits (modified from Blasland and Bouck 1989 in Effler 1996).

The park side sites (P-1, P-2) consisted mainly of broken porcelain fragments, pebbles, oncolites, and cobble sized particles on top of $CaCO_3$, sand/silt, and with **mats of algae**. Very few rooted macrophytes were observed at the park sites underlying substrate was very firm at both of the park sites

Sample sites were marked with a metal pole at each corner of a square with 4 **m sides to mark an area of 16 m** ^{2}. **This area was divided into a grid consisting of** sixty four 0.5 m sampling units (SU). Each SU was assigned a number from one to sixty four (Figure 6). SU numbers were selected by using a random number generator.

B.   *Field Sampling*

Samples were collected on three dates in 1989 (June 29, July 25, September 2) using a Portable Invertebrate Box Sampler (PIBS). **The sampler is a metal box open** on the top and bottom, with 350 μm mesh net on one side and foam pads on the bottom; it encloses an area of 0.1 m^2. The PIBS was held in place by an assistant in the appropriate sample square, orientated towards the open lake so that wave action would assist in pushing dislodged invertebrates into the trailing mesh bag. substrate enclosed by the sampler was agitated for five minutes by hand and pushed into a mesh bag. Pebbles, rocks, and other larger debris were rubbed gently inside the mesh bag to remove any invertebrates still attached to these surfaces. After 5 minutes the mesh bag was emptied into a whirl-pac and preserved with 75 - 80% ethanol Eosin Y dye was mixed with the ethanol to enhance visibility of invertebrates during **sample processing**. The water depth above the samples ranged from 10 cm to 60 cm.

Shore

|0.5 m|

1	2	3	4	5	6	7	8
9	10	11	12	13	14	15	16
17	18	19	20	21	22	23	24
25	26	27	28	29	30	31	32
33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48
49	50	51	52	53	54	55	56
57	58	59	60	61	62	63	64

0.5 m

4 m

4 m

Open Lake
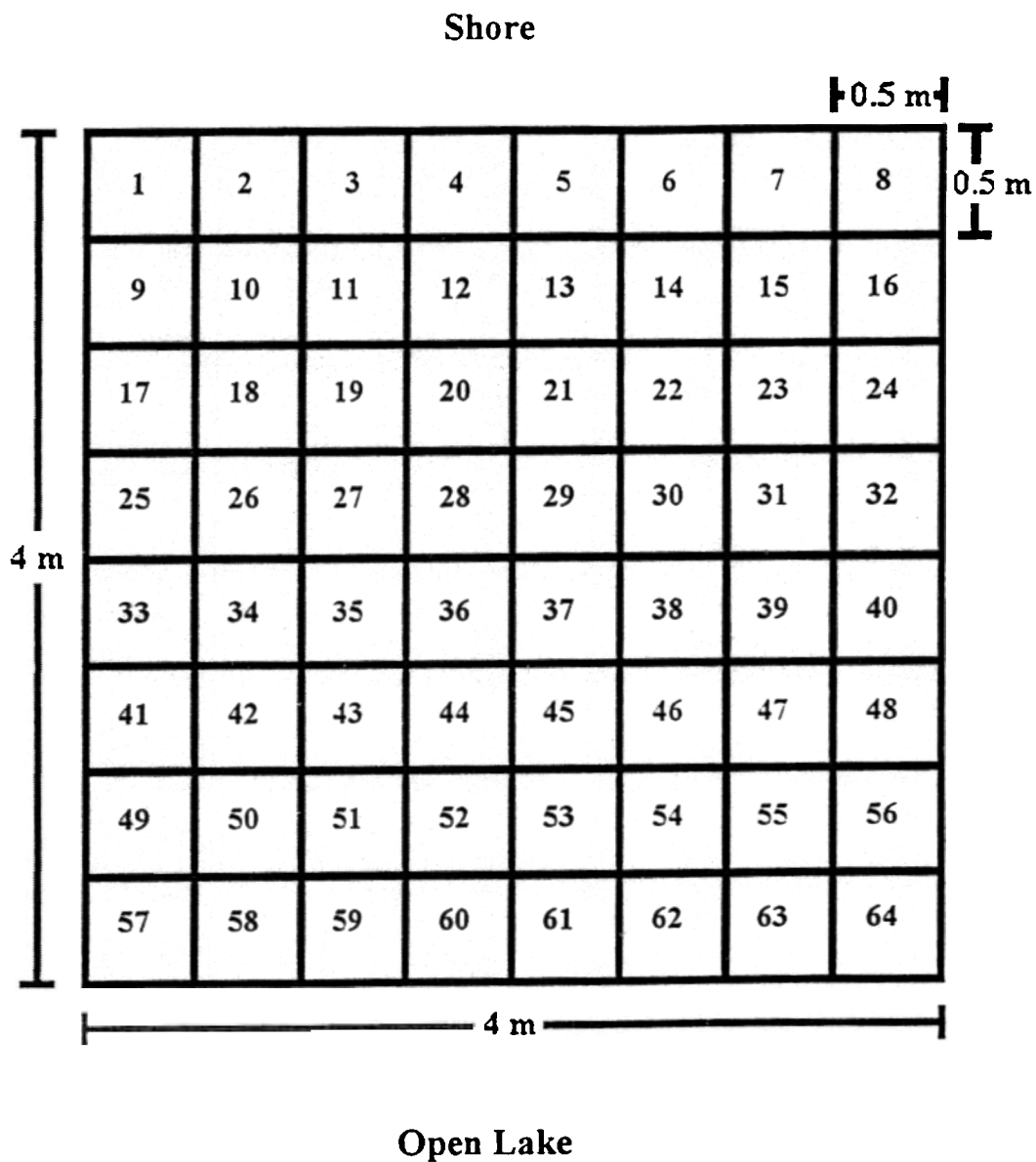
Figure 6. Sampling grid consisting of 64 half-meter sampling units (SU) and corresponding numerical assignments.

C. *Onondaga Lake Water Quality Monitoring*

Water quality data were collected weekly at the "South Deep" sampling station (Figure 2). The data collection was part of the Onondaga Lake Water Quality Monitoring program of 1989 conducted by Upstate Freshwater Institute (UFI). A YSI Model 57 Oxygen meter and a Montedoro/Whitney Model TC-5 Thermistor were used to collect data at 0.5 m intervals over the entire 19.5 m water column. Water samples were collected and returned to the UFI laboratory for further analysis. Secchi disk measurements, incident radiation profiles, phytoplankton, and zooplankton samples were also collected. The Upstate Freshwater Institute has conducted water quality studies on Onondaga Lake since 1980.

D. *Laboratory Procedures*

The samples were washed through a 100 µm-mesh sieve with tap water to remove silt and finer particles. Separation of organisms from debris was accomplished by scanning the samples immersed in tap water in a white enamel pan under 10x to 20x magnification with a Bausch and Lomb stereomicroscope. Because of the varying amounts of surface sediment and filamentous algae the sample processing times ranged between 8 - 36 hrs. All macroinvertebrates were identified to species, when possible, and enumerated. Identifications were made under 20x to 400x magnification using published keys (Peckarsky et al. 1990, Merritt and Cummins 1984, Pennak 1984, Simpson and Bode 1980, Thorp and Covich 1991, and Brinkhurst 1986). After enumeration, all organisms were stored in labeled vials in 80% ethanol and glycerin.

Because large numbers of chironomid larvae were encountered, sub-samples of 100 larvae from three sample sites were mounted in cmc-9 mounting media using a method similar to that described by Beckett and Lewis (1982); these sub-samples were enumerated and identified to species. Numbers obtained from these sub-samples were converted to percent composition. The oligochaetes in the samples tended to break apart upon preservation and storage. Therefore, only the head sections were counted. Microfaunal organisms collected in the samples included Ostracoda,, Cladocera, Copepoda, and Bryozoa these were not quantified. Fish eggs and larval fish were collect in the June 29 samples only but were not counted. Several of these fish larvae were identified to be carp

Representatives of mounted chironomid larvae were reviewed by Dr. Robert Bode of the New York State Health Department, Albany NY, to confirm proper identification of the larvae. Mounted specimens of oligochaetes were identified in an oligochaete and chironomid identification workshop conducted at the New York Natural History Conference III (Albany N.Y.) in 1994.

Samples collected on June 29, 1989 were processed in the manner outlined above. Samples from July 25, 1989 and September 2, 1989 were sub-sampled using the following method. First, the sample bag was emptied into a 20cm square white pan and mixed gently by hand for approximately 5 minutes to attain a uniform distribution of organisms. An X-shaped divider was then used to subdivide the pan into four equal sections. One of these sections was chosen at random, transferred to another pan, and processed as described above. The number of organisms obtained

from the sub-sampling procedure were multiplied by four to obtain estimates of total

number of organisms in the whole sample. Water samples were analyzed at the UFI

laboratory for water quality parameters (Table 2).

Table 2. Partial list of Upstate Freshwater Institute Laboratory Analysis of
Onondaga Lake Samples for 1989. Sampling period: April, 03 - November, 27.
Frequency: weekly

	Profile Depths
Alkalinity	0,1, 2-18m (2m interval)
pH	''
Ammonia	''
Nitrate	''
Nitrite	
TKN	
POC	
TOC	
Chloride	
Sulfate	
SPR	
TP	
Turbidity	
Chlorophyll a	0,1, 2-10m (2m interval) ,16m
Iron	June 5- Oct, 17 Anoxic depths
Methane	''
Sulfide	

E.   Data Analysis

Estimates of total density (number of invertebrates /m^2) were calculated by

adding the numbers of all invertebrates in the sample and multiplying by 10. This was

done because the PIBS sampler encloses an area of 0.1m^2. For the July and

September samples the density values were multiplied by four to account for sub-

sampling, then multiplied by ten. To obtain density values for each site, all the samples

from that site were added together and the mean, standard deviation, variance and

coefficient of variation were calculated Confidence intervals (95%) were constructed

around the mean by using the equation:

$$C.I. = \bar{x} \pm t_{,} \quad * S_{:} \qquad \text{(Zar 974)}$$

The density values were converted to percent composition to make comparisons

between site and date. This analysis was performed at each of the sampling sites and

for each of the three sampling dates.

An unbalanced four x three (site x date) analysis of variance (ANOVA) way

design with no interactions in the General Linear Model (SAS 1989) was used to

analyze mean density, log(mean density) diversity richness and chironomid percent

composition data. An arcsine (Zar 1974) transformation was used on the chironomid

percent composition data A nonparametric rank test (Kruskal – Wallis) was

preformed by using a log(x + 1) transformation on the density data tests. This was

done because of concern over model assumptions (normality of distribution) of the

density data. The Krukal – Wallis method was used because it is robust and easy to

perform and comprehend. System for Elementary Statistical Analytical (SAS 1989)

software was used to calculate the ANOVA and rank test results.

The Shannon diversity index, H', (Shannon and Weaver 1949) and Pielou's

evenness, J (Pielou 1966, 1975) were calculated for each sample using the basic

program SPDIVERS.BAS (Ludwig and Reynolds 1988), which use equations

$$\hat{H}' = -\sum_{i=1}^{s}\left[\left(\frac{n_i}{n}\right)\ln\left(\frac{n_i}{n}\right)\right]$$

$$J' = H'/\ln(S)$$

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where n_i is the number of individuals belonging to the ith of S species in the sample and n is the total number of individuals in the sample. Species richness *(NO)* was determined by actual number count and was also recorded for each sample and date. To obtain values for these community parameters the same summation procedure was used as in the calculations for density. Additionally, the data were pooled to obtain values that represented a given site on a given date. The samples from a given site and date were averaged together and the total number of taxonomic groups (total number of taxa per site per date) from all the samples within the site and date were added. This was done because the mean number of taxonomic groups (richness) was not representative of the total number of taxonomic groups found at the given site (Table 3). Regression analysis of H' against $ln(NO)$ and H' against J' was constructed to determine if there is a correlation between these components. The relationships between H' vs. $ln(NO)$ and H' vs. J' can give an indication of community stability (Tramer 1969). This regression analysis was performed on all the samples together as one data set.

Bray-Curtis (1957) ordination techniques were used to analyze pooled means from each site using the basic program PO.BAS (Ludwig and Reynolds 1988) to compare the similarity of the four sites through time. PO.BAS (Ludwig and Reynolds 988) calculates X,Y coordinates to use in the construction of a two-dimensional ordination graph. The summation of prominence values (PV) was used as the diameter around each point. Values from the total number of taxa per site per date data set (pooled) were combined in series of matrices used to develop a trellis diagram

employing the Renkonen number as similarity coefficient (Wallwork 1970) to assist in

the determination of relationships among sites and dates.

Table 3. Summary of sample size (n), minimum, maximum, mean, and total number taxa recorded at each site.

Date	Site	N	Min	Max	Mean	Pooled Taxa
06/29	W-1	6	6	10	7.5	11
	W-2	6	7	10	8.3	11
	P-1	6	9	11	10	15
	P-2	6	8	11	9.2	11
07/27	W-1	3	8	9	8.7	12
	W-2	3	7	10	8.3	11
	P-1	3	10	14	11.7	15
	P-2	3	9	10	9.3	13
09/02	W-1	3	1	13	12	17
	W-2	3	8	12	10	13
	P-1	3	7	12	10.3	15
	P-2	3	8	11	10	13

IX. Results

A.   Macroinvertebrate Density and Species Composition

1   June 29

The total mean densities (macroinvertebrates·m^{-2}) for this sampling date were

13,431 at P-1, 10,878 at W-2, 7,723 at P-2, and 5,573 at W-1 (Table 4). Kruskal –

Wallis test results for the June data set showed there was a significant difference

between mean density for the four sites (p = 0.0205: α=0.05). Chironomid larvae

were numerically dominant, reaching 93% - 95% at the waste bed sites and 58% -

69% at the park sites (Figure 7). Only five species of chironomid larvae were found in the June 29 samples: *Cricotopus sylvestris, Chironomus decorus, Glyptotendipes lobiferus, Tanytarsus guerlus*, and *Parachironomus abortivus*. Of these five, three species (*C. sylvestris, C. decorus*, and *G. lobiferus*) accounted for more than 95% of the total mean densities at all four sampling sites (Figure 8). Oligochaetes (Enchtraeidae) comprised between 22% - 36% of the total mean density from the park sampling sites. At the waste bed sampling sites they only accounted for 2.7% of the total density. The amphipod *Gammarus fasciatus* accounted for 3.4% - 5.3% of the macroinvertebrates. All remaining macroinvertebrates (Nematoda, Gastropoda, Turbellaria, Hydrachnidia, Odonata, Hemiptera, and Bryozoans) were combined into a group labeled "Other", which accounted for 2.8% or less of the overall density. A listing of all species collected is summarized in Table 5

Table 4. Mean Density Standard deviation, and Coefficient of Variation (%) of Benthic Macroinvertebrates at Four Sampling Sites on Onondaga Lake, 1989.

	W-1	W-2	P-1	P-2
06/29/89				
AVG	557.33	1087.83	1343.17	772.33
STD	298.90	387.95	549.50	295.25
Var	8.93E+04	1.51E+05	3.02E÷05	8.72E÷04
CV	53.63	35.66	40.91	38.23
S.E.	313.79	407.27	576.88	309.96
d.f. = 5	t = 2.571			
07/25/89				
AVG	3143.7	2521.3	3931.4	2533.5
STD	954.01	524.08	646.34	1305.42
Var	9.10E+05	2.75E÷05	4.18E÷05	1.70E÷06
CV	30.35	2079	16.44	51.53
S.E.	2370.14	1302.05	1605.79	3243.21
d.f. = 2	t = 4.303			
09/02/89				
AVG	8752	1914.7	4428	2026.7
STD	4519.78	954.19	3288.36	644.14
Var	2.07E÷07	9.10E+05	1.08E÷07	4.15E÷05
CV	51.99	49.84	74.26	31.78
S.E.	11303.51	2370.61	8169.42	1597.75
d.f. = 2	= 4.303			

x 10 for #/m^2 S.E = +$t_{.025}$ (s/ n)

d.f = degrees of freedom
t = Critical value of t at $t_{.025}$

A   B   C

06/29   07/25   09/02

W-

P-

Legend   Chiro=Chironomidae   Olig=Oligochaeta
          Amp=Amphipoda   Other=Other
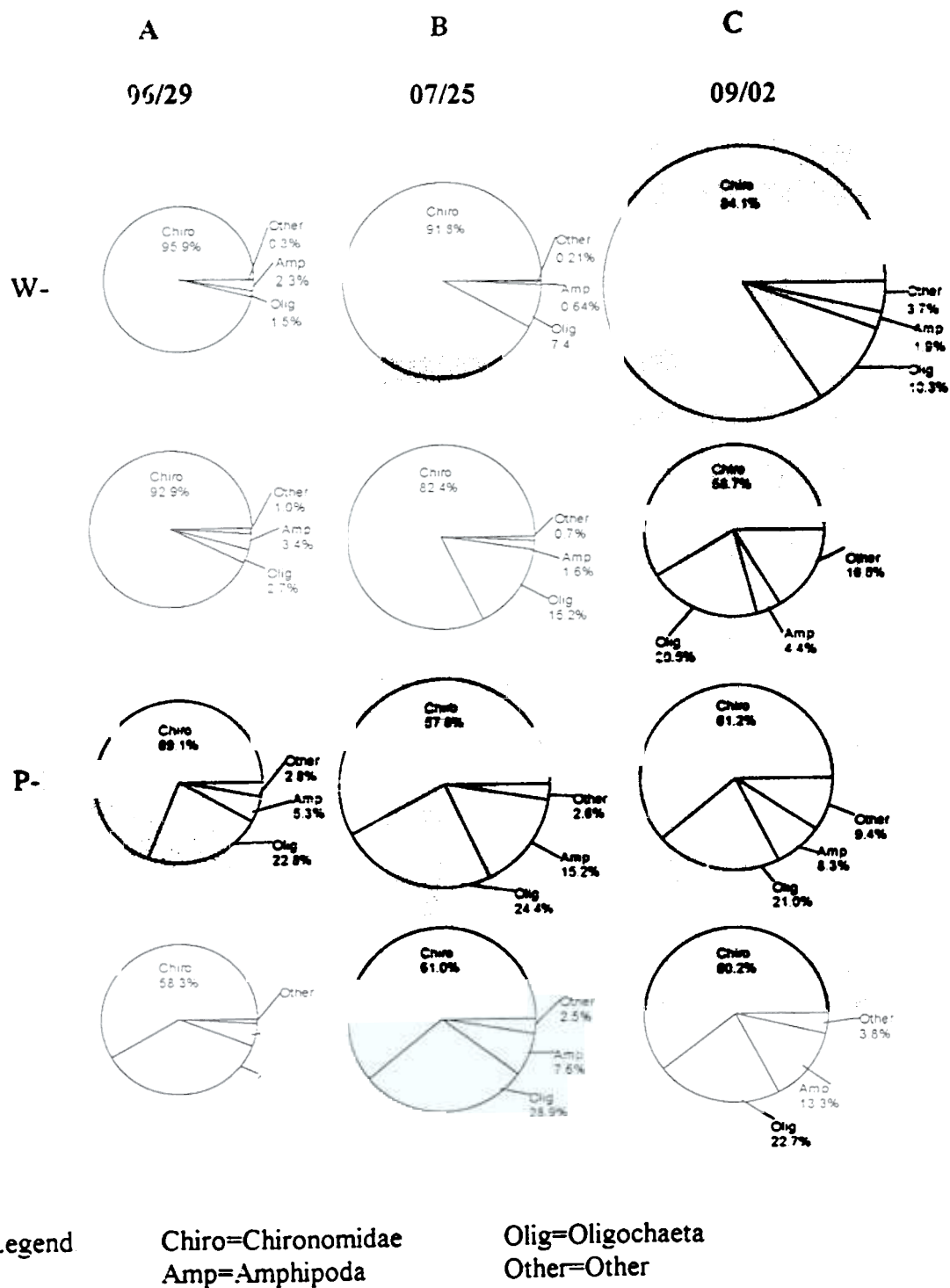
Figure 7. Overall macroinvertebrate species composition for Onondaga Lake.
    A) June 29, 1989 B) July 25, 1989 C) September 2, 1989.

Table 5. List of Nearshore Macrobenthic Organisms of Onondaga Lake, New York, 1989.

Platyhelminthes
  Turbellaria *spp.*
Nematoda
  Nematoda *spp.*
Bryozoa
  Plumatella repens
Annelida
 Oligochaeta
   Enchytraeidae
 Hirudinea
   Glossiphiidae
Mollusca
 Gastropoda
   Planorbidae Gyraulus
   Physella *spp.*
Arthropoda
 Crustacea
  Isopoda
   Caecidotea
  Amphipoda
   Gammarus fasciatus Say
 Arachnida
  Hydrachnidia
   Limnesia
 Insecta
   Collembola
   Odonata
     Coenagrionidae Coenagrion
   Hemiptera
    Corixidae
   Coleoptera
    Hydrophilidae
   Lepidoptera
    Acentria
   Diptera
    Ceratopogonidae
    Chironomidae
      Cricotopus sylvestris
      Chironomus decorus
      Glyptotendipes lobiferus

Table 5. (continued)

Tanytarsus guerlus
Parachironomus abortivus
Cladotanytarsus spp.
Rheotanytarsus spp.
Dicrotendipes nervosus
Procladius subettei

2.   July 25

The total density of macroinvertebrates per m^2 at all four sampling sites

increased between June 29 and July 25 The densities for this date were 39,314 at P-1

31,437 at W- , 25,335 at P-2 and 25,213 at W-2 respectively (Table 4). The Kruskal

– Wallis test showed that there was no significant difference among the means of the

four sites (p = 0.1540: α=0.05). Chironomid larvae accounted for the majority of the

macroinvertebrates in each sample; percentages ranged from 58% - 92% (Figure 7)

Six chironomid species were found in the July samples, with four of these species

occurring in the June samples as well. Two species, *Cladotanytarsus spp.* and

Dicrotendipes nervosus, appeared in the July samples, but were not present in June.

Although *P. abortivus* appears in the June samples, it was not found in the July

samples (**Figure 8**) Some chironomid larvae from this date could not be identified

because of the limited availability of taxonomic information on identification and the

additional difficulty of seeing characteristics in early instars These chironomids were

grouped into the category "Unidentified" (Und). Four species (*G. lodiferus, C*

sylvestris. C. decorus and *Tanytarsus spp.*) comprised the majority of the chironomid

larvae (>90%) The percentage of oligochaetes was greater at the Park sites (24% -

29%) than the Waste bed sites (7% - 15%). The percentages for *G. fasciatus* were also greater at the Park sites 8% - 15%. At the Waste bed sites the amphipod percentages were 2% or less. Mean percentages for the "Other" category included a 3% value at the Park sites and less than 1% at the waste bed sites.

06/29 **07/25** **09/02**

W-2

A **B** **C**
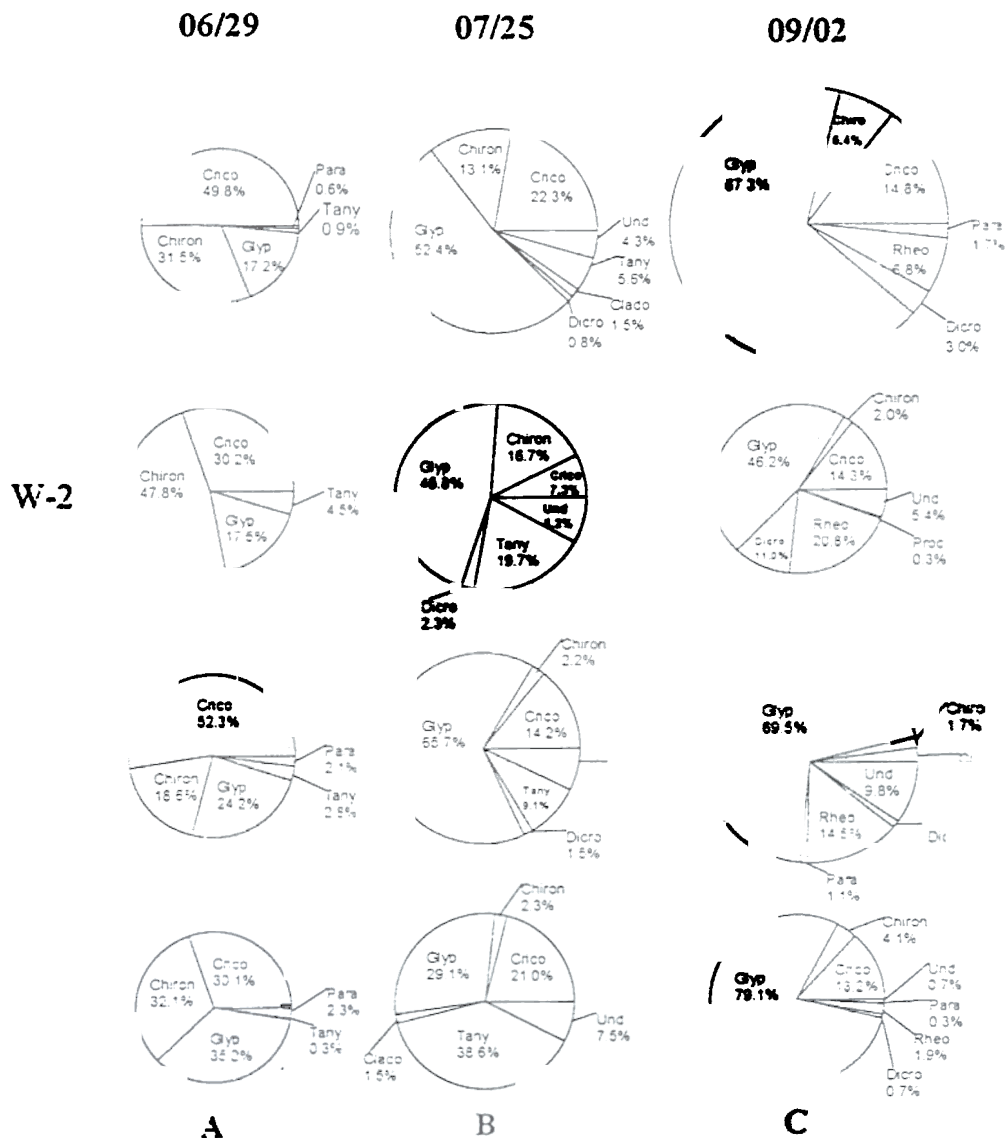
Legend   Crico=*Cricotopus sylvestris*   Chiron=*Chironomus decorus*
          Glyp=*Glyptotendipes lobiferus*   Tany=*Tanytarsus gurerlus*
          Para=*Parachironomus abortivus*   Clado=*Cladotanytarsus spp.*
          Rheo=*Rheotanytarsus spp.*   Dicro=*Dicrotendipes nervosu.*
          Proc=*Procladius subetti*

Figure 8. Chironomid species composition for Onondaga Lake   A) June 29,
   1989 B) July 25, 1989, C) September 2, 1989.

3 September 2

The total mean density for all four sites do not appear to be different from each other according to the Krukal – Wallis test (p=0703: α=0.05). Temporal and spatial mean density trends for the three sampling dates are summarized (Figure 9) Chironomid larvae were still numerically dominant (Figure 7). Seven species of chironomid larvae were recorded from this date, including two previously unreported species. *Rheotanytarsus spp.* and *Procladius sublettei.* Two species from the earlier sampling dates, (*G. lobiferus, C. sysvestris*), along with *Rheotanytarsus spp.* accounted for most of the chironomids present in the samples (81% - 94%) (Figure 8). The mean percentage of oligochaetes changed slightly at both sites. The "Other' category mean percentages increased from the June and July sampling dates at all sites.

The ANOVA results from all of the mean sample densities from each site and from each date showed a significant difference between mean density values for the four sites over time (p = 0.0001; α=0.05) but there was no significant difference between sites (p = 0.0788; α=0.05). ANOVA results from the log(density) data were also different over time (p = 0.0001; α=0.05) and not among sites (p = 0.1157; α=0.05).

Chironomid percent composition ANOVA demonstrated overall differences between both sites (p = 0.0001; α=0.05) and dates (p = 0.0001; α=0.05) To further refine the difference another ANOVA was run on park sites vs. waste bed sites; there

were significant differences for both between park and waste bed sites ($p = 0.0001$; $\alpha=0.05$) and dates ($p = 0.0003$; $\alpha=0.05$).
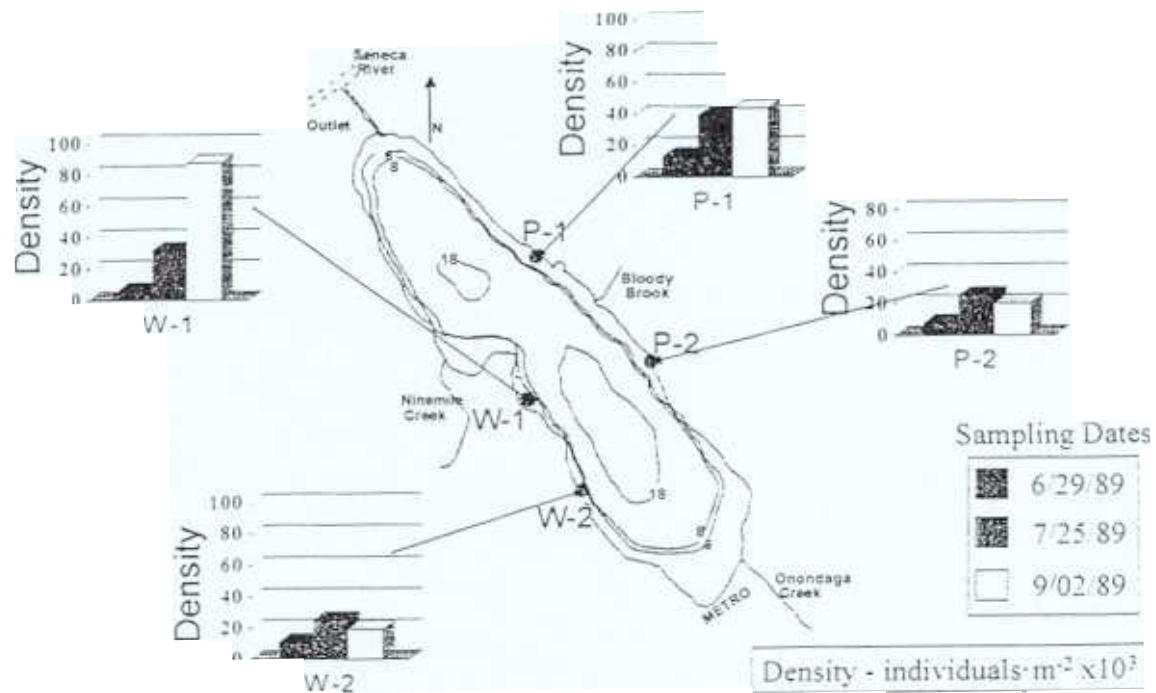
Figure 9. Summation of temporal and spatial density 1989 Onondaga Lake N.Y.

B.   *Macroinvertebrate Diversity, Richness and Evenness*

The mean diversity values *(H')* along with the associated standard deviations and coefficients of variation were calculated for each site and date (Table 6). Confidence intervals were constructed using two standard deviations about the mean and plotted (Figure 5) Two ANOVA tests were preformed on the diversity data. The first included all sites and all dates which showed that the diversity was significantly different among sites ($p = 0.0005$; $\alpha=0.05$), but was not significantly different over time ($p = 0.1762$; $\alpha=0.05$) The second combined the park sites together and the waste bed sites together (park vs. waste bed) The results were that the (park vs. waste bed) were significantly different ($p = 0.0005$; $\alpha=0.05$)

The species richness ANOVA results showed that richness overall was significantly different over time ($p = 0.0114$; $\alpha=0.05$) and just barely between sites ($p = 0.0546$ $\alpha=0.05$). Park vs. waste bed were significantly different between site ($p = 0.0234$; $\alpha=0.05$) and date ($p = 0.0234$: $\alpha=0.05$). Evenness only appeared to be different between sites ($p = 0.0073$; $\alpha=0.05$)

Mean values, standard deviations, and coefficients of variation for both species richness *(NO)* and evenness *(J')* were summarized by site and date (Table 8) The mean richness and evenness values do not appear to have changed between June and July The W-2 mean richness value remained the same, but the confidence interval increased in range. In September the mean species richness of sites W-2, P-1, and P-2 remained similar to the June and July mean values The site W-1 mean richness value did increase and was statistically different from the July mean value The mean

evenness values obtained for September did not change greatly from the June and July

mean values

Table 6. Mean Shannon Diversity Index H' (ln), Standard deviation, and Coefficient of Variation (%) of Benthic Macroinvertebrates at Four Sampling Sites on Onondaga Lake, 1989.

Site	06/29	N=6		07/25	N=3		09/02	N=3	
	x	STD	CV	x	STD	CV	x	STD	CV
W-	228	.063	5.130	1.394	.085	6.098	.412	.0164	11.615
W-2	.405	133	9.466	1.552	143	9.216	.819	.030	1.649
P-1	.633	.091	5.573	.485	.0247	16.633	.554	.298	19.2
P-2	1.572	.091	5.788	1.596	.076	4.762	1.473	.077	5.227

Table 7. Mean richness (NO), Standard deviation, and Coefficient of Variation (%) of Benthic Macroinvertebrates at Four Sampling Sites on Onondaga Lake 1989.

Site	06/29	N=6		07/25	N=3		09/02	N=3	
	X	STD	CV	x	STD	CV	x	STD	CV
W-	7.5	.1.52	20.0	8.67	0.58	7.0	12.00	1.00.	0.8
W-2	8.33	.03	12.0	8.33	1.53	18.0	10.00	2.00	20.0
P-1	10	.79	18.0	11.67	2.08	18.0	9.50	3.54	37.0
P-2	9.17	.1.17	13.0	9.33	0.58	6.0	10.00	1.73.	17.0

Table 8. Mean Evenness (J'), Standard deviation, and Coefficient of Variation (%) of Benthic Macroinvertebrates at Four Sampling Sites on Onondaga Lake. 1989.

Site	06/29	N=6		07/25	N=3		09/02	N=3	
	x	STD	CV	x	STD	CV	x	STD	CV
W	0.617	0.044	7.10	0.646	0.025	3.90	0.570	0.072	12.70
W-2	0.655	0.055	8.30	0.742	0.124	16.70	0.799	0.082	10.30
P-	0.714	0.023	3.20	0.612	0.143	23.30	0.673	0.074	11.00
P-2	0.713	0.037	5.20	0.716	0.051	7.10	0.644	0.019	3.00

C   Community Stability

The regression of H 's. $ln(NO)$ showed low (R squared = 0.1684) correlation between diversity and species richness (Figure 10). On the other hand the correlation for H' l's. J' was greater (R squared = 0.5631 (Figure 1). These regressions were performed with values from each sample (n = 48).These results indicate that H' is more closely correlated to species abundance rather than to species number

H' vs ln (NO)

$R^2 = .1684$

$y = 0.4017x + 0.6083$
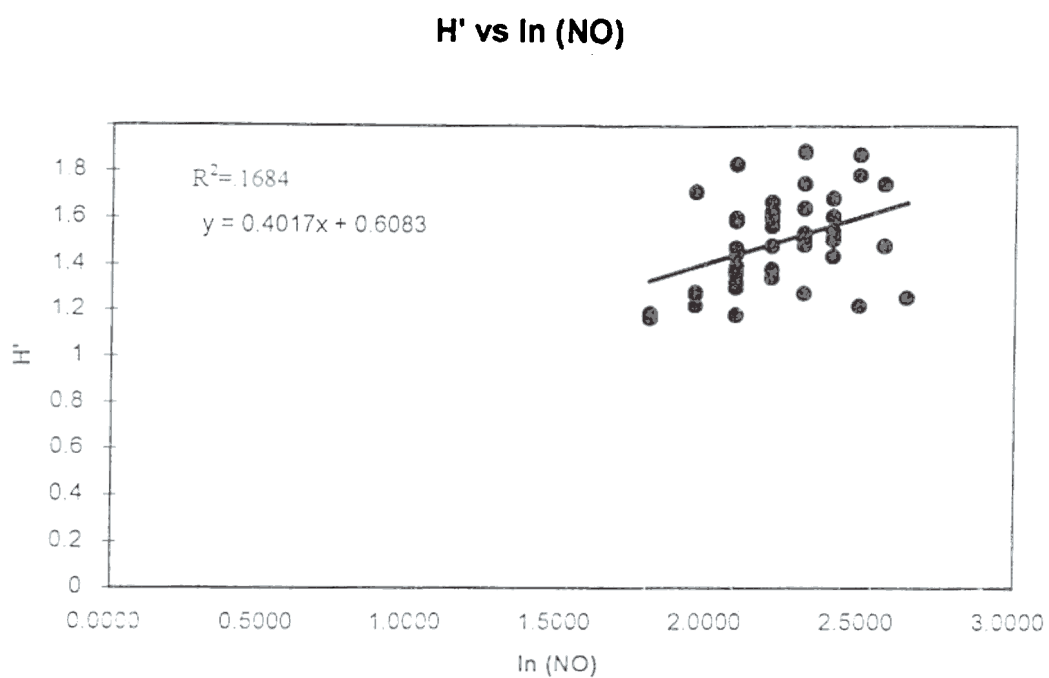
Figure 10. A regression of *H' Vs. ln(NO)* showing the correlation between macroinvertebrate diversity and species richness in Onondaga Lake, NY.
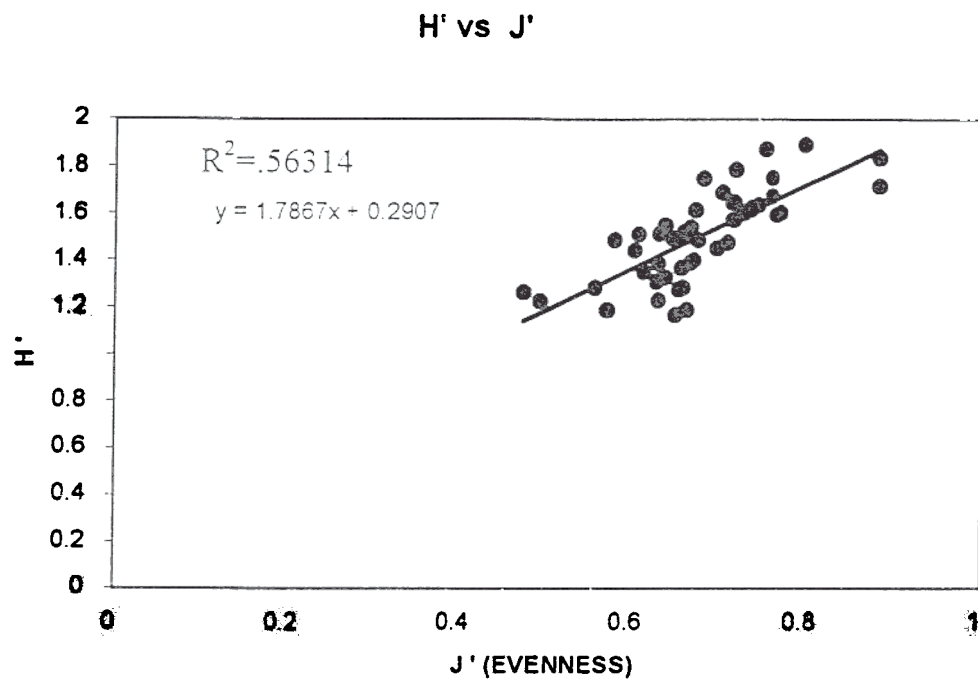
H' vs J'

Figure 11. A regression of *H' Vs. J'* showing the correlation between macroinvertebrate diversity and evenness in Onondaga Lake, NY.

D.   *Ordination*

Two dimensional Bray-Curtis techniques were used to create an ordination of the four sites with respect to time (Figure 12). In general, the P- , P-2 and W-1 grouped together by site than by date. However, the two park sites are more similar to each other than to the waste bed sites. The sampleW-2 from September appears to be more similar to the P-1 site group than any other sites.

E.   *Trellis Diagram*

The results for the trellis diagram are that the waste bed sites tend to be more similar to each other and park sites tend to be more with each other. This appears to be consistent with the Bray- Curtis ordination The June samples from all the sites are more closely grouped (more similar) than the later dates (Figure 13).
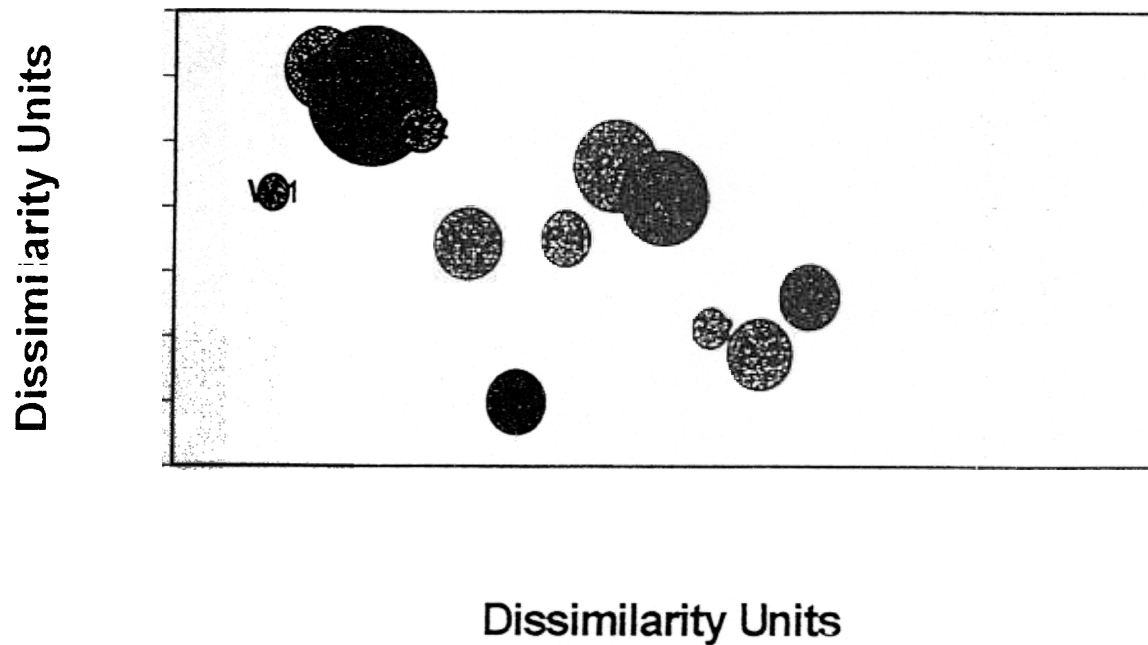
Figure 12. Bray-Curtis ordination of species densities across sampling sites in
Onondaga Lake, NY. Diameter of circle represents total density prominence
values at a given site and date. Green circles represent samples from 6/29/89,
blue circles represent samples 7/25/89, and red represents samples from
9/2/89. P designates park sites and W designates waste bed sites.
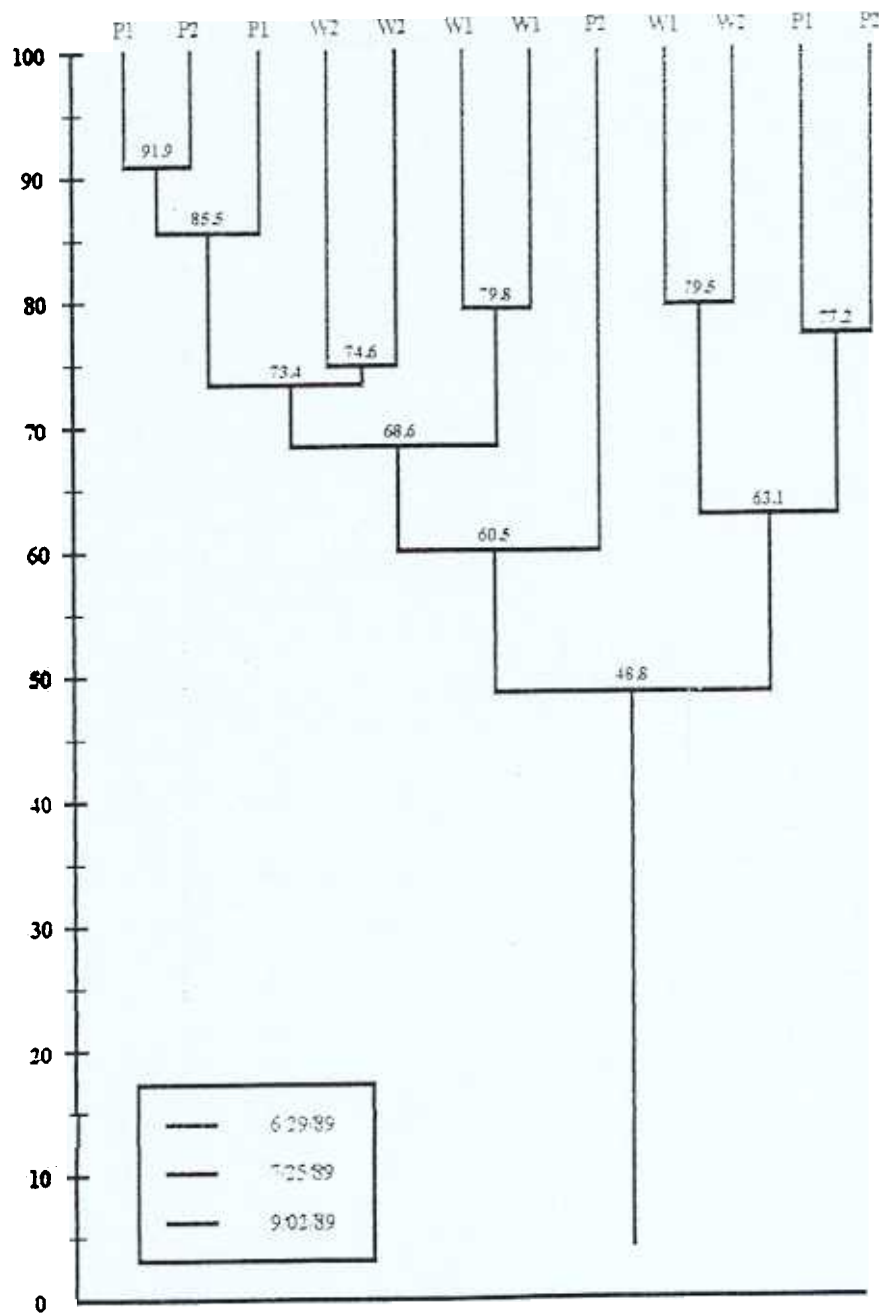
Figure 13. Trellis diagram of macroinvertebrate species density in Onondaga Lake, NY, 1989. P designates park sites and W designates waste bed sites.

X.   Discussion

The total number of species present in the wave zone macrobenthos of

Onondaga Lake is relatively low when compared to other lakes in the region (Table 9).

The wave zone communities of Onondaga Lake are numerically dominated by

chironomid larvae. All nine of the chironomid species collected in the wave-zone are

classified as pollution tolerant (sewage, ionic) (Roback1974, Simpson and Bode 1980,

and Hellawell 1986). With regard to the trophic relationships seven of the species are

collector/gathers or filter feeders (Coffman and Ferington 1984). Two other species,

Procladius subettei and *Paraachironomus abortivus,* are considered to be predaceous

(Coffman and Ferington 1984). These predatory forms are considered to be rare in

Onondaga Lake, only comprising at most two percent of the chironomid total. All of

these chironomid larvae construct tubes for feeding and shelter. These tubes are firmly

attached to the substrate and are resilient to wave action. The firm attachment to the

sediment may be one explanation for the high proportion of chironomid larvae (>90 %

of the species), at the waste bed sites.

The distribution of oncolites and waste bed deposits along with other factors

have had adverse effects upon the macrophyte community by reducing the species

richness from a historical high of 20 species to the current number of five macrophyte

species and by reducing percentage cover (Madsen et al   996). Madsen attributed this

reduction in plant species richness to the high solute concentration, high calcium

carbonate ($CaCO_3$) precipitation, limited sediment fertility and the unstable nature of

the oncolites.

The orientation of Onondaga Lake and the substrate instability may also

contribute to differences between sampling sites. Onondaga Lake is oriented along a

northwest-southeast axis. This orientation exposes the lake to almost constant wave

action from the prevailing west winds. Wave action moves and redistributes silt.

Table 9. Selective Comparison of Onondaga Lake Wave Zone Macrobenthos Species Richness to Results Reported for Other Systems

Lake	Wave-Zone Depth (m)	Species Number	Trophic State	Source
Huron 1974	0-2	205	Oligotrophic	Barton and Hynes 1978
Superior 1974	0-2	194	Oligotrophic	
Georgian Bay 1974	0-2	192	Oligotrophic	
Erie 1974	0-2	170	Mesotrophic	
Ontario 1974	0-2	165	Oligotrophic	
Oneida 1916-18[a]	0.46-1.8	83	Eutrophic	Baker 1918
Conesus 1975	0-1.5	71	Mesotrophic	Wade and Walker 1975, Walker 1975
Oneida 1916-18[b]	0.46-1.8	45	Eutrophic	Baker 1918
Cayuga 1973[c]	3-4	43	Mesotrophic	Dahlberg 1973
Cayuga 1988[d]	0.10-0.75	30	Mesotrophic	Ringler and Wagner 1988
Onondaga 1989	0.10-0.60	25	Hypereutrophic	This study

[a] Sandy bottom
[b] Gravel bottom
[c] oligochaetes counted as one group
[d] Chironomids counted as one group

detritus and oncolites between the spaces of the heavier cobble and benthic algae of

the park sites. The build up of silt and detritus (organic material) in these spaces

provides a more suitable habit for oligochaetes (Brinkhurst 1986, Brinkhurst and Gelder 1991). The wave action tends to scour away the less dense waste bed chunks, exposing a hard surface. In other cases the wave action can break up the chunks into sand sized particles. It was observed that the benthic algae mats of *Cladophora* were thick and covered larger areas of the substrate at the park sites. The *Cladophora* growth was thin and sparse, at the waste bed sites. The thicker mats of *Cladophora* could be trapping more organic matter for the oligochaetes. The increase of detritus along the park side may contribute to the increased abundance of oligochaetes found at these two sites.

The zooplankton assemblage of Onondaga Lake has changed in response to the changes in the ionic loading (Cl^-, Na^+ and Ca^{2+}) to the lake from Allied Chemical soda ash/ chlor-alkali facility (Siegfried et al. 1996). Siegfried et al. (1996) attributed the major shifts in the zooplankton assemblage to the reduction in the salinity, and the attendant precipitation of calcium carbonate associated with the closure of the industry Siegfried stated that the major shifts were that the number of common species increased from eight to eighteen and that larger and more efficient grazers became dominant in the assemblage. These major changes occurred in 1987 within one year of the closure of the Allied Chemical soda ash / chlor-alkali facility. In the years prior to the closure (1968-1985) the average salinity of Onondaga lake was 3 4‰. Aquatic habitats that have salinity in this range exhibit greatly reduced species diversity due to the effects on osmoregulation capabilities of freshwater invertebrates Remane Schlieper 1971, Wetzel 1983). From 1986 to the present the average salinity

has remained relatively constant at 25‰. This lower level of salinity can support a greater diversity of invertebrate species (Remane and Schlieper 1971). In studies of Lake Lenore WA, where the salinity declined over time, the highest colonization rates of new species were at salinity between .9 – 2.8‰ (Wiederholm 1980) (Table 10)

Table 10. Maximum Species Richness at 0-2.5M in Lake Lenore, Washington 1957-1975

Year:	1957	1962	1971	1975
Salinity	6.7	2.8	1.9	1.6
No. of Species	8	9	22	25

adapted from Wiederholm (1980)

The taxonomic groups that dominate the fauna of Onondaga Lake (*Chironomus spp*, *Cricotopus spp*, *Glyptotendipes spp*, oligochaetes and the Amphipod *Gammarus fasciatus*) can tolerate a wide range of salinity (Rawson and Moore 1944, Bousfield 1973, Hammer et al. 1975, Wiederholm 1980), depending on the ion composition (Hammer et al. 1975). Sodium bicarbonate lakes tend to have lower species richness at the same salinity than sodium magnesium sulfate lakes (Rawson and Moore 1944, Hammer et al. 1975, Wiederholm 1980, Pinder 1986) Groups that dominate the benthic fauna of Onondaga Lake may do so, in part, because of their high tolerances to salinity.

The $CaCO_3$ precipitation rate (particle production) was artificially high prior to closure (Driscoll et al. 1994, Womble et al. 1996). These concentrations exceeded those known to inhibit the reproduction of daphnids (0.8 mm /L; Vanderploeg et al

987). This rate of CaCO$_3$ precipitation was high enough to coat the bodies of cladocerans (Garofalo and Effler 1987) and may contribute to increased rates of respiration (Siegfried et al.1996). The ingestion of high amounts of nutrient poor CaCO$_3$ particle by filter feeding invertebrates may also increase respiration rates because of the energy required to process (ingest and transport through digestive tract) and transport added weight (Vanderploeg et al. 1987) without any nutrient benefit The calcium levels have been greatly reduced (from a mean of 565mg/L to 154mg/L) since the closure of soda ash/ chlor-alkali facility, but remain at elevated levels relative to near by waters (Effler 1996).

The fish community of Onondaga Lake has shifted from a coldwater fishery to warmwater fishery over the past 200 years due to industrial and cultural pollution (Tango and Ringler 1996). Currently there is rather high species richness (54 species) in the lake This high species richness is believed to be the result of the lake's connections to refugia (from stressful lake conditions) in the Seneca River (Tango and Ringler 1996). At least twelve of these species could be considered to be macrobenthic invertebrate feeders (Table 1) and nine of these species reproduce in Onondaga Lake (Ringler et al 1996,Gandino 1996, Arrigo 1998). These invertebrate predators may have had some effect on the larger bodied species such as crayfish. Predatory fish in lotic systems can impact the relatively rarer, larger (>8mm) bodied invertebrates without greatly affecting overall community structure (Flecker and Allan 1984) No record of crayfish species from Onondaga Lake has been found in the literature. nor did any signs (body parts) appear in any of the sampling during this

investigation. Crayfish also do not appear in the diet study results of Onondaga Lake fish (Ringler et al. 1996). However, crayfish species are present in the Seneca River up stream and down stream of the lake and in the lower section of Ley Creek above Park St. (personal observation). It would appear that crayfish have been absent from the lake for some time.

Table 11. Benthic Invertebrate Feeders

Species	Reproduce in Lake
Lepomis gibbosus (Pumpkinseed)	
Lepomis macrochirus (Bluegill)	
Catostomus commersoni (White Sucker)	
Moxostoma macrolepidtum (Shorthead Redhorse)	
Cyprinus carpio (Carp)	
Micropterus dolomieui (Smallmouth Bass)	+
Micropterus salmoides (Largemouth Bass)	+
Perca flavescens (Yellow Perch)	+
Ictalurus punctatus (Channel Catfish)	
Ictalurus nebulossus (Brown Bullhead)	+
Aplodinnus grunniens (Freshwater Drum)	
Ambloplites rupestris (Rock Bass)	

Onondaga Lake has elevated concentrations of ammonia as a result of effluent from the Metropolitan Syracuse Sewage Treatment Plant. One of the more toxic

compounds associated with this type of this pollution is free ammonia (NH_3. In the

upper epilimnion the concentrations of this species can exceed 0.26 mgN L^{-1} (Effler

1996). This concentration can be considered harmful to fish when occurring with

higher pH values (USEPA 1985), but this concentration is below the published values

known to be harmful to benthic invertebrates (0.93-22.8 mgN L^{-1} (USEPA 1985)

Freshwater clams generally have the lowest tolerances and crayfish the highest. In

contrast to the case for fish and most invertebrate species, free ammonia becomes less

toxic to the amphipod *Hyalella azteca* at higher pH if the alkalinity is also high

(Ankley et al. 1995). These conditions of high pH high and alkalinity occur commonly

in Onondaga Lake during phytoplankton blooms in the summer months. It could be

possible that some of the other invertebrate species common to Onondaga Lake may

be responding in a similar manner to the hard water conditions of the lake. Although it

may seem that the effects of NH_3 might be minor when considered alone, when it

combined with all the other stress factors (high salinity, high $CaCO_3$ precipitation

unstable substrates and predation), it may have a significant role in determining the

macrobenthic invertebrate community structure of Onondaga Lake. All these stress

factors, along heavy metal pollution and some other yet to be undetermined stresses.

may combine to form a environment that is too degraded to support populations of

Ephemeroptera, Trichoptera and Decapoda.

The diversity of the macrobenthic community of Onondaga Lake is poorly

correlated with species richness. This poor relationship has been described (Tramer

969. Pielou 1966) in communities occupying perturbed habitats. Tramer (1969)

suggested that these types of environments are rigorous ones which vary widely and often unpredictably in climate and / or resources. Collections of organisms from rigorous environments will vary in diversity according to their relative abundance distributions (evenness) where as diversity patterns in collections from non-rigorous environments will be a function of the numbers of species (Tramer 1969). The wave – zone communities of Onondaga Lake do seem to exhibit highly variable patterns of species abundance as reflected in the density data.

The Bray-Curtis ordination results seem to indicate that the parks site are more similar to each other both temporally and spatially and W-1 remains similar to itself over the sampling season. Site W-2 appears to change greatly over time This may reflect similar water quality and physical conditions between the park sites over time. W-1 also seems to be stable over time but, the water quality and physical conditions at W-2 maybe less stable The very soft sediment immediately adjacent to site W-2 may have some effect upon this site.

The Trellis diagram shows that the June samples appear to be more similar with each other than any of the other dates This could be an indication that water quality conditions in Onondaga Lake were uniform lake wide prior to the June sampling.

XI. Recommendations

Monthly sampling (April – October) of other littoral and deep waters habitats for at least one year to establish baseline information for other habitats in the lake. Repeat sampling every three – five years or after any major water quality improvements to see the invertebrate communities responses to changes.

2) Measure the total macroinvertebrate biomass at several sites around the lake and combine with fish diet studies conducted at these same sites to determine if there are any spatial differences in biomass around the lake.

3) Analyze the benthic invertebrates and their predators, the near-shore water column, and near-shore sediments at different locations for metals and other possible contaminants to measure rates of bioaccumulation in the food web.

XII. Conclusions

The wave-zone communities of Onondaga Lake are characterized by low species diversity and low species richness These communities are dominated by chironomid larvae and oligochaetes, with a few other pollution tolerant invertebrate groups comprising the remainder of the benthic fauna The pollution tolerant groups dominate in part, because of their high tolerance to the unnatural elevated salinity conditions that have prevailed in Onondaga Lake over this past century Common groups such as Trichoptera, Ephemeroptera and Decapoda are conspicuously absent from the lake's wave-zone. These observations portray the wave-zone habitats of the lake as highly impoverished communities This depauperate community structure is a result of the severe environmental degradation of the water quality and benthic habitat that is unique to the Onondaga Lake ecosystem. The wave-zone communities will remain in this poor condition until the water quality and the near-shore habitat improve.

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Experience

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Upstate Freshwater Institute	1987-present	Research Scientist
Institute of Ecosystem Studies	1986	Poglar Fellowship
Institute of Ecosystem Studies	1985	Summer Fellowship
SUNY Research Center at Oswego	1984-1985	Fisheries Technician
SUNY School of Environmental Science and Forestry	1984	Fisheries Technician
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